

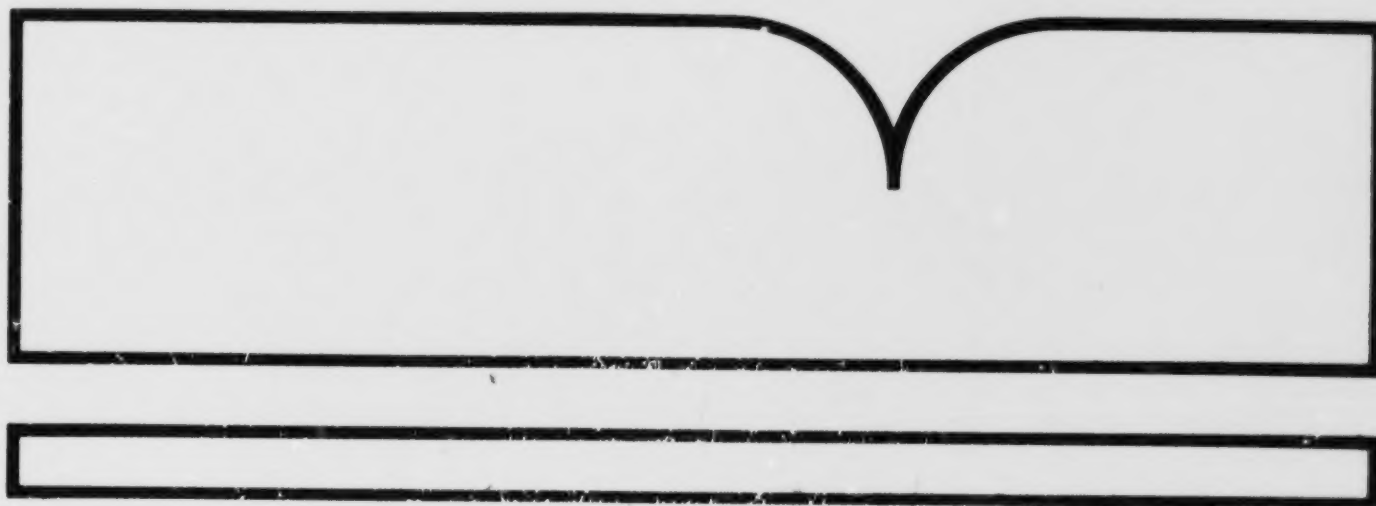
Modeling Water Quality and the Effects of
Agricultural BMPs (Best Management
Practices) in the Iowa River Basin

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AGRICULTURAL BMPs IN THE IOWA RIVER BASIN

by

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OF AGRICULTURAL BMPs IN THE IOWA RIVER BASIN

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ABSTRACT

This paper describes a demonstration application of comprehensive hydrology and water quality modeling on a large river basin to evaluate the effects of agricultural nonpoint pollution and proposed best management practices (BMP). The model application combines detailed simulation of agricultural runoff and soil processes, including calculation of surface and subsurface pollutant transport to receiving water, with subsequent simulation of instream transport and transformation. The result is a comprehensive simulation of river basin water quality.

The investigation of the Iowa River Basin described in this paper was part of a large study which included application and evaluation of the Hydrological Simulation Program - FORTTRAN (HSPF) to both the data-intensive Four Mile Creek watershed and the Iowa River above Coralville Reservoir. In this study, the methodology developed on Four Mile Creek was extrapolated to the Iowa River Basin to demonstrate its applicability and functionality on a large river basin. Many model parameter values from Four Mile Creek were applied directly to the study area without adjustment while other parameters were modified based on available information and calibration. This study allowed the exploration of problems associated with modeling hydrology, sediment, and chemical fate and transport in a large river basin with varying meteorologic conditions, soils, and agricultural practices.

KEYWORDS

Runoff; erosion; sediment transport; pesticides; nutrients; agricultural BMPs; basin-scale modeling; water quality modeling.

INTRODUCTION

Mathematical models are being used to analyze and predict the quantity and quality of runoff from agricultural lands. The ultimate goal is to use these models to develop a Best Management Practice (BMP) plan that will maintain agricultural productivity while minimizing adverse water quality impacts. However, runoff models by themselves are not sufficient to predict water

quality effects of BMPs since instream transport and transformations are not represented. These models must be linked with receiving water quality models to assess the quality in receiving waters resulting from BMPs applied to the watershed.

The investigation of the Iowa River Basin described in this paper was part of a large study which included application and evaluation of the Hydrological Simulation Program - FORTRAN (HSPF) (Johanson et al. 1981) to both the data-intensive Four Mile Creek watershed (Donigian et al. 1983a) and the Iowa River Basin above Coralville Reservoir (Donigian et al. 1983b). In this study, the methodology developed on Four Mile Creek was extrapolated to the Iowa River to demonstrate its applicability on a large river basin. Many model parameter values from Four Mile Creek were applied directly to the study area without adjustment while other parameters were modified based on available information and engineering judgement. This study allowed the investigation of HSPF capabilities to simulate hydrology, sediment, and chemical fate and transport in a large river basin with varying meteorologic conditions, soils, and agricultural practices.

BASIN DESCRIPTION

The portion of the Iowa River Basin modeled in this study encompasses an area of 7240 km² in Central Iowa, and terminates at the Coralville Reservoir near Marengo, Iowa (Fig. 1). The river later joins with the Cedar River before emptying into the Mississippi. There are three distinct topographical areas in the watershed. The upper portion is gently rolling to flat with poor drainage and is characterized by depressions which collect water and prevent rapid runoff. The central area is more hilly, and the southern portion is relatively level. Elevations range from 900 to 1200 feet. Most of the basin is covered with prairie soil formed from glacial drift; in the lower portions, loess covers the glacial drift. Soils in the basin are primarily loams and silty clay loams. The soil associations are Clarion and Webster in the upper areas, and Tama-Muscataine in the lower portion. The climate in the basin is humid with average temperatures of 47 degrees and mean annual precipitation of 32 inches. Land use is primarily agricultural with about 45% in corn cropland, 22% in soybeans, and 33% in other uses, primarily pasture.

DATA COLLECTION AND WATERSHED SEGMENTATION

Meteorologic, streamflow, and water quality data necessary to calibrate HSPF were selected and examined, along with soils characteristics, topography, and land use information, in order to segment the Iowa Basin. Variation in precipitation and air temperature over the basin indicated that the Iowa River Basin could be divided into three segments, in order to perform a reasonable hydrologic simulation for the purposes of this demonstration study. Tentative boundaries for the segments, based on long term isopleth information on rainfall and air temperature, were then adjusted slightly based on spatial distribution of soils. Three NOAA/NWS weather station records (Sheffield in the north, Iowa Falls in the central area, and Traer in the southeast) were selected as most representative of the precipitation on these segments based on comparison of long term averages. Similarly, the air temperature stations chosen were Iowa Falls, Marshalltown, and Cedar Rapids. Additional time series required for hydrologic calibration of HSPF are wind speed, potential evapotranspiration, and solar radiation. Single data sets were used to represent these quantities over the entire basin

because of limited variation and/or availability of data. The segment boundaries and locations of meteorologic stations used for the simulation are shown in Fig. 1.

Final subdivision of the three segments into pervious land segments (PLSs) was based on land use. Between 65% and 85% of each county in the basin is cropland, and only grassland comprises more than 10% of the total usage. Most of the croplands are planted in either corn or soybeans. Given the differences in fertilizer and pesticide applications for the two crops, separate land uses were assumed. All lands not planted in corn or soybeans were considered as a third composite land use. Thus, a total of nine PLSs were modeled - one to represent each of the three land use types in each of the three meteorologic/soil segments.

Streamflow data was available for nine U.S.G.S. gages in the basin; however, only three were located on the main branch. Daily sediment loadings collected by the U.S. Army Corps of Engineers at Marengo were used, along with limited (grab samples, etc.) water quality data obtained from the U.S. EPA.

The main channel of the Iowa River between the confluence of the east and west branches and the U.S.G.S. gage near Marengo was divided into 13 reaches for simulation. Of the 12 intermediate reach boundaries between the study limits, one was selected at the Iowa Falls Power Dam channel discontinuity, two were selected at U.S.G.S. streamflow gage sites (Rowan and Marshalltown), eight corresponded to sites of major tributary inflow, and one was chosen arbitrarily to subdivide a long section of the river. The 13 reaches and contributing area to each are illustrated in Fig. 2.

HYDROLOGIC/HYDRAULIC SIMULATION

A limited calibration effort was undertaken in this study in order to demonstrate sufficient agreement between model results and available data so that the model could be used for preliminary BMP analysis and evaluation. In general, an accurate hydrologic calibration is necessary since errors in the hydrology directly impact the chemical and sediment simulations.

Initial hydrologic simulations were performed on two test watersheds in order to provide preliminary adjustments to the parameter values developed for the Four Mile Creek watershed. Differences in the soils and topography between the upper and lower parts of the basin indicated that significant changes would be necessary. The watersheds were the East Branch of the Iowa River above Klemme in the northern extreme of the basin and Salt Creek above Elberon in the southern portion (near Four Mile Creek). Based on these initial simulations, a number of parameter adjustments were made prior to the first basin-wide simulation.

In addition, adjustments were necessary to the meteorologic data for the basin-wide simulation. Long-term meteorologic patterns in each segment group were compared with the mean characteristics at each of the stations used for the simulation. Based on this comparison, multipliers were developed and applied to the precipitation and temperature time series.

A limited hydrologic calibration effort (three simulation runs) was made to further adjust the parameter values until an acceptable basin-wide hydrology simulation was obtained. Table 1 provides comparisons of recorded and simulated runoff at the three U.S.G.S. streamflow gages along the Iowa River



Figure 1. Segment Boundaries and Locations of Meteorological Stations in the Iowa River Basin.



Figure 2. Channel Reaches and Contributing Areas for the Iowa River Basin.

for the five year simulation period (1974-1978). Representative results for simulated mean daily flow are shown in Fig. 3. Simulated runoff volumes for the first four years of the study period were generally fair to good at the three gages. The final set of hydrologic parameter values resulted in a fairly consistent oversimulation of runoff at Rowan by approximately 15-20% prior to 1978. Simulated runoff at Marshalltown and Marengo was less than observed for this period. Undersimulation at Marshalltown was generally in the range of 20-25% of recorded annual totals, while Marengo was within 5% of recorded runoff for the years 1975-1977.

TABLE 1 Hydrology Simulation Results (expressed as runoff in mm)

	ROWAN		MARSHALLTOWN		MARENGO	
YEAR	REC	SIM	REC	SIM	REC	SIM
1974	154.	183.	313.	232.	391.	321.
1975	152.	124.	216.	169.	234.	228.
1976	59.*	80.	136.	107.	139.	138.
1977	9.*	49.	65.	67.	98.	95.
1978	102.	300.	169.	297.	227.	348.
TOTAL	477.	734.	899.	874.	1089.	1129.

REC - recorded

SIM - simulated

* - does not include 10/76-6/77 runoff; data not available

Runoff for the year 1978 was drastically oversimulated due to problems with the Sheffield precipitation record which was used to represent the upper segment group. Recorded rainfall totals for two storms in June and July of that year were 84 mm and 114 mm in 12 and 5 hours, respectively. It is unlikely that rainfall of comparable intensity occurred on the entire segment. Overall, simulated runoff for 1978 at Rowan was 190% greater than recorded, resulting in a 76% oversimulation downstream at Marshalltown and 53% at Marengo. Similarly, during an August 1974 storm, the rainfall recorded at Iowa Falls and Traer was not nearly enough to induce the large flow recorded at Marengo. These discrepancies indicate the problems associated with using a single rainfall record to represent a large segment of land.

Another major problem with the hydrologic simulation was the timing and volumes of snowmelt runoff. Modeling snow accumulation, melt, and resulting runoff is a traditional weakness in watershed modeling. For example, the occurrence and effects of frozen ground conditions are not well defined quantitatively, but they exert major impact on snowmelt runoff. We attempted to account for frozen ground effects by reducing infiltration during the winter months. Simulated runoff from snowmelt generally preceded recorded values in the Iowa Basin. In most years the snow pack melted in a short 2-3 week period producing a peak flow in about mid-March; the model generally produced a more gradual melting and lower peak flows. These problems are likely due to deficiencies in the model and input meteorologic data, primarily air temperature and solar radiation.

For the purposes of this demonstration study, comparison of recorded and

simulated flow frequency data provides an adequate indication of the acceptability of the simulation results. Fig. 4 shows the simulated and recorded flow frequency curves for the 1974-1978 period at Rowan, Marshalltown, and Marengo. This figure indicates that modeling results for the upstream gage at Rowan were not good; simulated mean flow was over 50% greater than recorded mean flow. However, since only 15% of the basin area is above the Rowan gage, simulation results for this gage are not as important as results at the downstream gages at Marshalltown and Marengo. At the lower gages simulated flows had a much better fit to recorded values; mean simulated flows at both gages differed from mean recorded flows by less than 5%. While these statistics verify that the simulated flows were acceptable for the purposes of this study, additional calibration is recommended if the information developed in this study is to be used for planning decisions in the study area.

SEDIMENT SIMULATION

Separate HSPF module sections were used to simulate detachment/removal of sediment from the land surface and instream sediment transport processes. In both cases, initial parameter values were taken directly from the Four Mile Creek study. Since recorded sediment erosion data were not available anywhere in the basin, adjustments to parameter values were made on an intuitive basis following an initial run in which erosion was obviously too low; three calibration runs were made. The final sediment erosion simulation showed a total washoff of 2.7 tonnes/ha for the five year simulation period. Totals for the nine segments were as follows:

	SOYBEANS	CORN	PASTURE/OTHER
UPPER BASIN	5.4	5.4	0.8
MIDDLE BASIN	0.8	1.1	0.06
LOWER BASIN	5.2	5.6	0.7

The totals for the upper watershed were biased by the high 1978 erosion which was caused by the large oversimulation of runoff in this area. In a year with good fit between simulated and recorded runoff, such as 1974, approximately 80% of the total basin washoff emanates from the lower area, 17% from the middle area, and only 2% from the upper portion (as opposed to 49% in 1978). This distribution is more reasonable considering the topography, soils, and relative amounts of area in the three portions of the basin. The upper area is characterized by low overland flow slopes and depressions which retard runoff and trap eroded sediment. The hilly terrain of the middle portion enhances erosion. The effects of the gentler slopes of the lower basin area are overcome by larger quantities of rainfall and much more erodible soils than are found in the northern areas. Consequently, a large fraction of the sediment washoff emanates from the lower area.

Instream sediment transport is a complex problem, and effective calibration with HSPF requires data to characterize the depth and composition of the bed sediments as well as particle hydraulic characteristics and recorded storm suspended particle size distributions. For the Iowa River, the only available data were daily sediment loadings at Marengo.

Three instream sediment calibration runs were performed, using the sediment washoff as loading to the channel, and starting with parameter values developed in Four Mile Creek. Parameters were adjusted until a reasonable fit to recorded data for 1974 was achieved. The results are illustrated in Fig. 5, where the flow simulation is shown for comparison; loadings for the

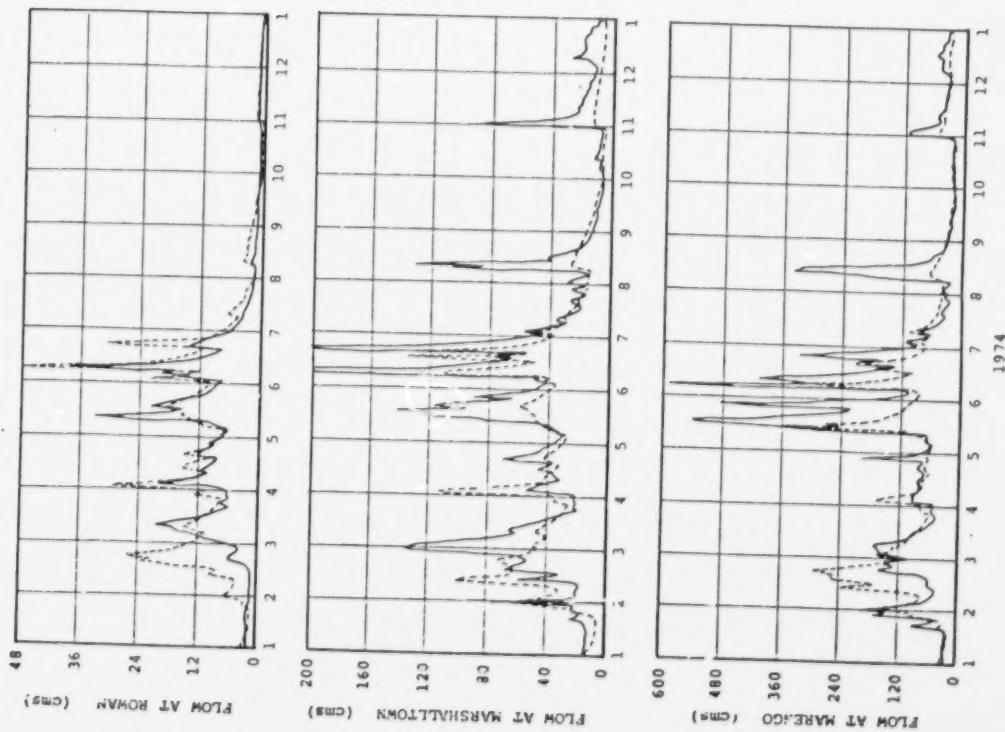


Figure 3 Comparison of Flow Simulation Results with Streamflow Records at Rowan, Marshalltown, and Marengo, Iowa

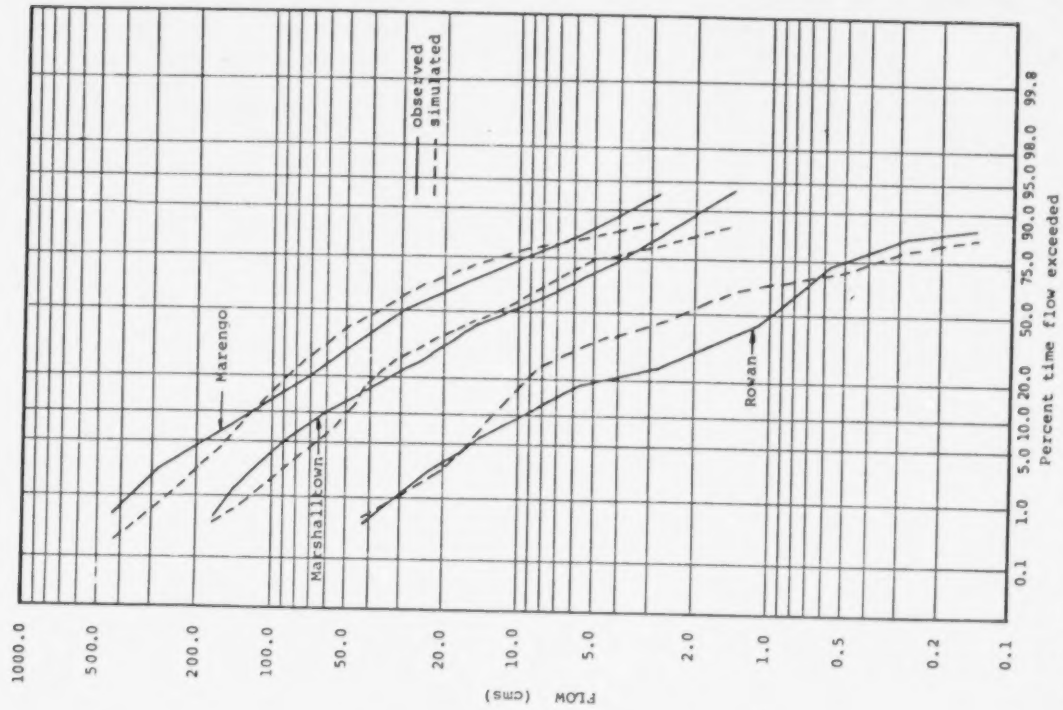


Figure 4 Comparison of Simulated and Observed Flow Frequency at Rowan, Marshalltown, and Marengo, Iowa (1974-1978)

entire simulation period are provided in Table 2. Generally the sediment calibration results were fair to good considering the lack of recorded erosion data and information for characterization of the sediment bed, and discrepancies between recorded and simulated streamflow. A major question of the simulation concerns the source of loadings at Marengo; simulated results showed 14% of the 1974 total resulted from surface washoff while the remaining loadings resulted from channel scour.

TABLE 2 Sediment Simulation Results at Marengo

YEAR	SEDIMENT (kg/ha)		
	RECORDED	SIMULATED	SIMULATED *
1974			
January	28.	5.	4.
February	190.	984.	20.
March	227.	66.	4.
April	203.	375.	13.
May	1432.	509.	140.
June	1380.	1952.	354.
July	247.	11.	8.
August	245.	2.	1.
September	7.	0.	0.
October	6.	0.	1.
November	69.	1.	0.
December	13.	0.	0.
TOTAL	4047.	3905.	545.
1975	1501.	875.	207.
1976	1233.	559.	74.
1977	332.	19.	17.
1978	1802.	5690.	1880.

* Edge of stream loadings - included for comparison.

PESTICIDE SIMULATION

The herbicide alachlor was simulated in order to demonstrate HSPF capabilities for modeling chemical fate and transport in the Iowa Basin. Alachlor is used extensively on corn and soybean cropland in the basin, and it had been modeled previously in Four Mile Creek. However, the simulation was limited by lack of recorded alachlor concentration data in the basin.

Alachlor simulation with HSPF involved applications to corn and soybean cropland, adsorption to soil, degradation, dissolved and adsorbed transport to streams, and instream adsorption, decay, and transport. Land surface and instream pesticide parameters were used directly from the Four Mile Creek HSPF application; no calibration was performed due to lack of data. During the five year simulation period, significant alachlor runoff to the river system occurred only in May-July since the alachlor half-life of 6-15 days depleted the 2.8 kg/ha application amount to less than 0.25 kg/ha by mid July. Typical simulated instream alachlor concentrations during storms were in the range of 10-100 ppb during these months. No recorded data were

available in the study area; however, alachlor concentrations recorded downstream of Coralville Reservoir during 1975 and 1976 showed maximum values of 1.0 and 1.7 ppb (Schnoor et al. 1979) compared to simulated values upstream of 27. and 17. ppb. This range of concentrations is also consistent with data on other Iowa streams (Schnoor et al. 1982).

NUTRIENT SIMULATION

Edge-of-stream nitrogen nutrient loadings were calculated by the land portion of HSPF and used as input to the stream section for instream simulation in order to calculate the nutrient loadings and concentrations downstream at Marengo. The processes modeled were application of fertilizer and plant residue in chemical form to the land surface or incorporated into the soil, the complete soil nitrogen cycle as represented in HSPF, adsorption/desorption, nutrient movement with soil and water to the stream, instream transport, and ammonia volatilization and nitrification.

The nutrient simulation followed the same general procedure as the pesticide simulation. Parameters were adopted from Four Mile Creek and used in conjunction with the watershed hydrology and stream hydraulics to model nutrients in the basin for 1974-1978. Simulated nitrate and ammonia concentrations at Marengo and Marshalltown for 1978 are illustrated in Fig. 6. Limited observed data at nearby sampling sites are included for comparison. Since the simulated nutrient concentrations are generally in the same range as observed values, the results are good for a model application without calibration.

BMP EFFECTS ON WATER QUALITY

The effects of a proposed BMP scenario were simulated to analyze the resulting impacts on water quality. The effects of the chosen BMP (conservation tillage plus contouring) on model parameters were estimated (Donigian et al. 1983c) and the model was run with the adjusted parameters with subsequent comparison to the base conditions.

The primary components of the BMP scenario were (1) a shift from moldboard plowing to chisel plowing and field cultivation as primary tillage, (2) one summer cultivation for weed control instead of two, and (3) allowing crop residues to remain on the field following harvest. These components were modeled by increasing parameter values for soil moisture retention (UZSN), rainfall interception, surface roughness (Manning's n), and land cover; and decreasing the sediment fines produced by tillage. There were no changes in the infiltration parameter, chemical parameters, soil bulk density, soil temperature, or chemical application amounts, although fall fertilizer application was replaced by increasing the spring and summer applications.

Using these assumptions and associated changes in parameter values, the resulting comparison of this BMP scenario and the base conditions is shown in Tables 3 and 4 for 1974. Over the simulation period, annual runoff reductions from corn and soybean cropland ranged from 4% to 17%. Surface runoff decreased significantly with average reductions of 30% and 26% for corn and soybeans. Corresponding sediment losses, which come entirely from the surface were also reduced dramatically (52% and 47%). BMP effects on erosion were much more pronounced than the resulting loading since most of the simulated sediment loading at Marengo resulted from channel scour rather than land surface erosion.

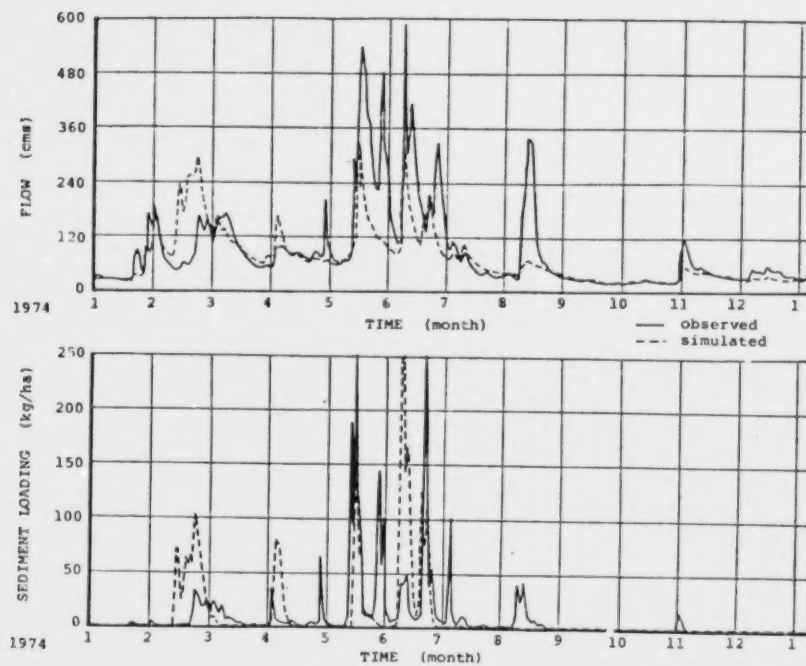


Figure 5 Comparison of Simulated and Recorded Flow and Sediment Load near Marengo

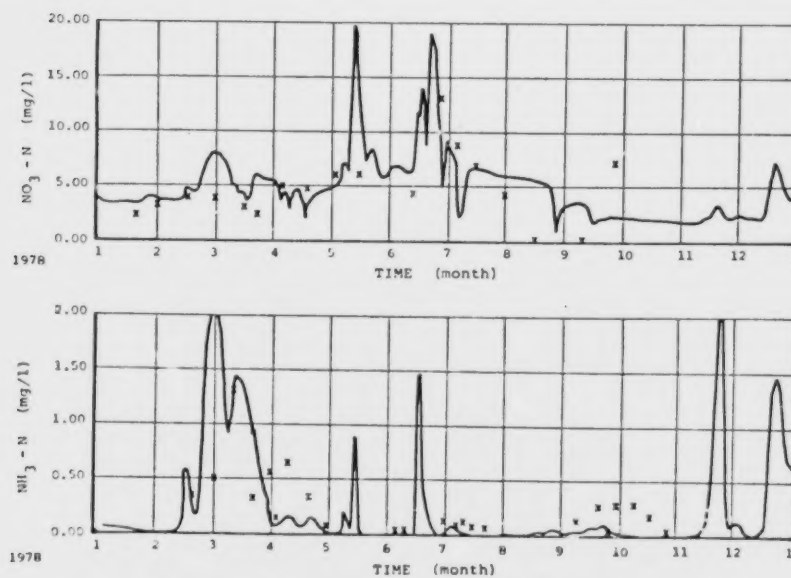


Figure 6 Comparison of Simulated and Recorded Nutrient Concentrations near Marengo

TABLE 3 Comparison of Edge-of-Stream Loadings for Base Condition and BMP Simulations in 1974

SOYBEANS			CORN		
BASE	BMP	% CHANGE	BASE	BMP	% CHANGE
RUNOFF (mm)					
Surf.	32.	23.	42.	31.	-25.
Intf.	51.	44.	59.	53.	-11.
Grndw.	205.	202.	212.	202.	-4.5
Total	288.	269.	312.	296.	-8.3
SEDIMENT	0.61	0.34	0.90	0.60	-33.
(tonne/ha)					
ALACHLOR	0.091	0.063	0.19	0.15	-19.
(kg/ha)					
NITRATE (kg/ha)					
Surf.	0.036	0.025	0.120	0.073	-39.
Intf.	2.6	2.4	16.2	15.5	-4.
Grndw.	20.7	20.2	35.5	33.8	-5.
Total	23.3	22.6	51.8	49.4	-5.
AMMONIA (kg/ha)					
Surf.	0.16	0.12	0.77	0.56	-26.
Intf.	0.49	0.36	2.2	1.6	-29.
Grndw.	0.064	0.063	0.067	0.064	-4.5
Total	0.72	0.55	3.1	2.2	-28.

Surf. - surface runoff

Intf. - interflow runoff

Grndw.- groundwater runoff

The resulting effects of the BMP scenario on water quality in the river measured at Marengo are shown in Table 4. Over the five-year simulation period, total flow reductions at Marengo averaged 7.5% while sediment reductions averaged 21%. Total instream ammonia reductions were considerably greater than nitrate because reduced sediment erosion prevents adsorbed ammonia from reaching the stream while erosion control has limited effect on the mobile nitrate species.

TABLE 4 Comparison of Loadings at Marengo for Base Condition and BMP Simulations in 1974

	BASE	BMP	% CHANGE
Runoff (mm)	183.	170.	-7.1
Sediment (tonnes/ha)	3.9	2.6	-33.
Alachlor (kg/ha)	0.028	0.022	-21.
Nitrate (kg/ha)	31.	30.	-3.9
Ammonia (kg/ha)	0.48	0.41	-15.

One of the possible uses of continuous simulation modeling of chemical fate and transport is to evaluate the risk or exposure of aquatic organisms to various magnitudes and durations of chemical concentrations. Using a methodology developed by Onishi et al. (1979) to assess the risk of chemical exposure to aquatic organisms, the simulated alachlor concentrations under both base conditions and the BMP scenario were analyzed to determine the percent of time acute, chronic, and sublethal conditions would exist. The results of this analysis are shown in Table 5; the table title indicates a hypothetical organism because all the values observed for alachlor concentrations were considerably below any of the MATC (maximum acceptable toxicant concentration) values for common species of fish found in the Iowa River.

TABLE 5 Lethality Analysis of BMP Scenario for Alachlor in the Iowa River at Marengo, Iowa (Hypothetical Organism)

GLOBAL EXCEEDANCE (% of time)			
	BASE CONDITION	BMP SCENARIO	% CHANGE
ACUTE REGION	0.49	0.49	0.
ABOVE MATC VALUE	3.5	2.7	-23.
SUBLETHAL REGION (below MATC)	96.5	97.3	-0.8

As shown in Table 5, the specific choice of MATC and lethality data chosen for this analysis resulted in no change in the percent of time when acute conditions existed; a 23% reduction in time of chronic conditions was seen. Although the values listed here are specific to the conditions under which this BMP scenario was simulated, the analysis indicates how the procedures described here can be used to evaluate the effects of BMP scenarios on resulting risk of exposure of organisms to chemicals.

SUMMARY

This demonstration application of HSPF to the Iowa River Basin has shown that HSPF can be used to model the flow, sediment, and water quality (specifically pesticides and nitrogen nutrients) from large agricultural river basins. Extrapolation of parameter values from nearby or representative calibrated watersheds can be performed with a reasonable degree of confidence. Determination of representative meteorologic time series data, primarily precipitation and air temperature, for different portions of the basin is a critical component in basin-scale modeling. Lacking representative data, comparison of frequency information is a better measure of overall simulation accuracy than comparison of storm event data.

With minimal calibration effort, simulation of flow frequencies on the main stem of the Iowa River was fair to good in this study, in spite of problems with deficient rainfall data and with modeling volume and timing of snowmelt runoff. Sediment simulation was poor due to insufficient calibration, lack of data, and model deficiencies. Simulated alachlor loadings and concentrations in the Iowa River were in the expected range. Simulated nitrate and ammonia concentrations were usually within the range of observed

grab sample data.

The simulation of the Iowa River Basin would be improved with additional calibration, refinement of the sediment simulation through additional calibration, and verification of both hydrology and sediment simulation. Recommended improvements in HSPF include accomodation of nutrient and chemical inputs with precipitation, simulation of both ionized and un-ionized forms of ammonia and sediment-ammonia interactions, and better definition of river bed water quality and sediment processes.

This study has demonstrated that HSPF provides a flexible and realistic means of approximating the impacts (quantity and quality) of candidate BMPs in large river basins. However, true verification of the ability to simulate the effects of BMPs must await the availability of post-BMP implementation data.

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